PATENT SPECIFICATION

DRAWINGS ATTACHED

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COMPLETE SPECIFICATION

Improvements in or relating to X-Ray Shadow Microscopes with Adjustable Optical Focussing

We, PHILIPS ELECTRICAL INDUSTRIES LIMITED, of Spencer House, South Place, Finsbury, London, E.C.2, a British Company, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention relates to X-ray shadow microscopes provided with adjustable optical focussing.

An X-ray shadow microscope is an X-ray tube in which the focal spot, the source of the X-rays, is formed on a thin metal window and by means of which an image of a small article is produced on a display screen which is spaced away from the focal spot by a distance which is a multiple of the distance by which the article is spaced away from the focal spot. This focal spot must be very small, for otherwise the X-ray image is not sharp. The higher the required resolving power, the more exacting this requirement becomes. Such a small focal spot is obtained by focussing the beam of electrons travelling from the cathode to the window (the target) by means of a highly reducing electron-optical system.

By varying the energization of the electron-optical system or the shapes or mutual spacings of the system components, the image of a different sectional plane of the electron beam is projected onto the target each time. The problem is to reduce the sectional area of the beam on the target to a minimum by means of this variation. Thus, the correct adjustment is achieved.

To this end, one would like to observe the focal spot during the adjustment of the electron-optical system. However, since this cannot be done in a simple manner for a variety of reasons, use is frequently made of a metal gauze arranged adjacent the focal spot. The shadow which this gauze, when irradiated by X-rays, casts onto a fluorescent screen, is observed, the electron-optical system being adjusted so that the lines of this shadow image have maximum definition.

Owing to the comparatively low voltage by which, in an X-ray shadow microscope, the electrons are accelerated, the brightness of the fluorescent image is so small that the room in which the screen is arranged must be completely darkened and the observer must accustom his eyes to the darkness for a prolonged period of time before he can observe the image. With this low brightness, the instant at which, during the variation of the image, the lines are defined most sharply cannot be determined with certainty. Therefore, the conventional method of focussing adjustment must be regarded as insufficient. The present invention provides an improved arrangement.

An electron microscope is known in which an image of an article is produced on a pick-up screen by electrons which are reflected at the article. The electrons irradiating the article pass through the lens serving to produce an image of the article. Thus, this lens has two functions, that is to say, it increases the electron density at the article of which an image is to be formed and it produces an image of this article on a pick-up screen.

According to the present invention, the principle of operation of the said electron microscope is used to achieve a different purpose, namely to render the focal spot in an X-ray shadow microscope perceptible in order to enable this spot to be sharply adjusted.

According to the invention, there is provided an X-ray shadow microscope including an adjustable electron-optical image-producing system, wherein in operation a first beam of electrons travelling from an electron ejector to a focal spot on a target is reflected as a second beam of electrons from the focal spot, which second beam passes in operation through the optical system or through part of the stages which this system comprises and is collected on a fluorescent observation screen. This observation screen must be disposed at a point where, with correct adjustment, the lens produces an electron-optical image of the focal spot.

The electrons in the returning beam have

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different velocities, the greatest value of which is equal to the velocity at which the electrons travelling to the target reach this target. The curves which is a graphical representation of the amount of electrons per unit of time as a function of their velocities, has a peak at the value of this greatest velocity. The present invention utilizes the existence of this peak.

In an X-ray shadow microscope in which the axes of the system stages coincide with the beam axis, the electrons which return from the target with little or no energy loss, would retrace their original path. Thus, the observation screen must have an aperture of passage for the electrons going to the focal spot. This aperture forms a blind spot centrally of the image to be observed. If the size of this aperture is not excessive, at missadjustment of the objective, the returning electrons can be detected in a zone surrounding the beam travelling to the target by means of this screen. However, with the required adjustment of the objective, at the point of observation the image just falls within the beam travelling to the target and consequently is no longer perceptible.

In order to avoid the said blind spot, or at least to shift it from the centre of the image so that the observation is improved, the electron beam which is emitted from the target and passes through the optical system or through part of the stages which this system comprises, can be separated from the beam striking the target. This separation can be effected by magnetic fields which act upon the rays.

To achieve this beam separation, provision can be made of a magnet system which produces a magnetic field the lines of force of which are at right angles to the axis of the ray beam. When the electron-optical image-producing system includes a magnetic lens, the beams may alternatively be separated from one another by arranging this lens so that its optical axis is at a slight angle to the axis of the electron beam which travels from the cathode to the target.

Thus, an electrically conductive fluorescent screen may be interposed between the electron ejector and the magnetic lens, which screen has an aperture of passage for the electrons going from the cathode to the target and must be at a positive potential with respect to the cathode.

In order that the invention may readily be carried out, two embodiments thereof will now be described, by way of example, with reference to the accompanying drawings, in which:

Figure 1 shows diagrammatically the electron-optical system of an apparatus in accordance with the invention which is provided with a separate magnet system for the separation of the electron beams,

Figure 2 shows diagrammatically a system in which use is made of a lens disposed obliquely relatively to the beam axis.

Figure 3 illustrates the operation of the apparatus to which Figure 2 refers, and

Figure 4 shows a detail of the arrangement shown in Figure 2.

In Figure 1, reference numeral 1 designates the hot cathode of an X-ray shadow microscope. In operation, a voltage of the order of 10 kV is set up between this hot cathode and a target 2 which is a thin metal window in the end-wall of the X-ray tube. The target is positive with respect to the cathode. Adjacent the cathode, provision is made of at least one electrode 3, which is also at a positive potential with respect to the cathode for accelerating the electrons emitted by the cathode towards the target, and of a negative diaphragm 4 for concentrating the electrons. The electrons 1, 3 and 4 together constitute the electron ejector. The electrode 3 or the last electrode of the ejector system can be at the same potential as the target 2 and hereinafter will be referred to as the anode.

In the electrical or magnetic field of an electron lens 5, the electron paths are deflected so that they terminate in a very small focal spot 6 which usually is circular. From this focal spot, soft X-rays are emitted in every direction. The size of the focal spot not only depends upon the physical dimensions of the cathode, the relative spacings and the potential distribution, but also upon the lens adjustment. The diameter of the focal spot may be 1 micron or even less.

From the focal spot 6, electrons return through the lens 5 in a direction opposite to that in which the electrons travel from the cathode to the target. The electrons reflected with little or no loss in velocity might return to the ejector system under the action of the electron lens. However, a magnetic field is set up the field strength of which includes a component at right angles to the axis of the electron beam. This may be achieved by arranging the poles of an electromagnet or a permanent magnet one on each side of the beam so that it is subjected to the action of a transverse magnetic field. One of these magnet poles, which is assumed to be arranged behind the beam, is designated 7 in Figure 1. It is the south pole. The north pole (not shown) is disposed in front of the beam.

This transverse magnetic field produces a deflection of the paths of the electrons travelling from the ejector to the target. Since the paths of the returning electrons are deflected by the magnetic transverse field in the same sense of rotation, the returning beam 9 is detached in this field from the beam 8 travelling to the target and beyond the transverse field, goes its separate way. The change in focussing produced by the magnetic transverse field is very slight, so that the returning electrons are concentrated onto a small area surrounding a point 10 at which a collector plate

11 of conductive material is disposed. This collector plate is given a positive potential with respect to the cathode, for example, by connecting it to the anode 3.

The plate 11 is coated with a fluorescent material so that a visible image of the focal spot is produced. However, this image is many times the size of the focal spot itself, since it is magnified by the lens. The brightness of this image materially exceeds the brightness of the X-ray image by which the definition of the focal spot has been judged hitherto. Frequently, there will be no need for the observation of the focus image to be performed in a dark room. In some cases, the intensity of the X-rays will be insufficient to produce visible fluorescence of a fluorescent screen even in a completely dark room. In this event, the electron lens cannot be adjusted with the aid of an X-ray image, since there is no visible fluorescent X-ray image. Even in this case, the adjustment can be performed by the use of the invention which renders the adjustment independent of the X-ray image. The number of electrons returning from the target at a substantially undiminished velocity is even relatively increased at lower voltages (lower efficiency of the production of X-rays).

If the plate 11 is very thin, so that the electrons can penetrate through it, the fluorescent layer may be coated on the surface of the plate more remote from the target.

The image which is produced on the target at correct adjustment of the lens, is the image of the smallest beam cross-section. This smallest cross-section usually lies between a negatively charged diaphragm 4 arranged in front of the cathode and the annular or cylindrical anode 3 which is spaced away from the cathode by a slightly larger distance. In the above-mentioned electron microscope, the image produced in the image plane is an image of the plane in which the beam cross-section is largest.

In some cases, there is projected onto the target the image of the aperture in a diaphragm which is arranged in a field-free space and intercepts the emitted electrons but for a narrow beam.

Neglecting any deviations owing to lens defects, there is formed on the fluorescent material on the plate 11 a visible image which with respect to its shape and size is an exact copy of the beam cross-section, an image of which is produced on the target 2. The dimensions of the image on the fluorescent material will be small, however, with the aid of optical magnification its degree of definition can always be observed. The image also shows whether the arrangement of the electrodes of the ejector system relative to one another or to a lens must be corrected, since not only the definition but also the shape of the image can be examined. The spot which is visible on the fluorescent material on the plate 11 is evenly illuminated and, unlike the image produced by an electron-microscope, does not show a certain pattern.

Adjustment of the image definition can be very accurate. When the focussing of the ray beam from the electron ejector on the target 2 is not correct, but is such that the lack of definition cannot be observed visually on an X-ray screen, the image on the fluorescent coating on the collector plate 11 becomes visibly blurred and soon disappears when defocussing is continued. This is in part due to the fact that the defect in focussing is repeated on the way back.

If the image of the smallest beam cross-section is not produced on the target but, for example behind the target, the rays converging into a point of this image intersect the target in an area of finite size. By means of the returning electrons, this area produces an image at a point far beyond the collector plate 11, which image is produced by rays striking the collector plate through a considerable area so that any definition is out of the question.

Hence, a brightly illuminated and sharp spot becomes visible on the plate 11 only with accurate adjustment of the electron-optical system. Even at a slight misadjustment, the bright spot becomes a shapeless glimmer of appreciably attenuated fluorescent light of radially decreasing brightness.

Figure 2, in which parts corresponding to those of the arrangement shown in Figure 1 are designated by like reference numerals, illustrates an alternative method of separating the beam of returning electrons from the beam of electrons travelling to the target. In this embodiment, the magnetic lens 5, which is shown as a cylinder, is disposed so that its axis is at a slight angle of, for example, 0.5° to the axis of the electron beam. This lens can be assumed as being composed of a lens the axis of which lies in the plane of the drawing and of a magnetic pole pair producing a field the central vector of which is at right angles to the plane of the drawing. For the sake of clarity, these two components are shown separately in the equivalent diagram of Figure 3 in a projection according to an elevation from the left with respect to Figure 2. They are a true electron lens (having poles 12 and 13 and a winding 14) and a pair of poles 15 and 16. It is assumed that the direction of the energising current in the winding 14 is chosen so that 12 and hence 15 is a north pole and 13 and hence 16 a south pole. This implies a deflection of the beam 8 and of the beam of returning electrons to the right. Consequently, the latter beam leaves the lens in a different direction, as is indicated by 9. Although in actual fact the beam axes 17, 18 and 19 may not lie in one plane, as is assumed here, this is not important for an understanding of the operation of the apparatus. It will be appreciated that

in any case the beams 8 and 9 diverge from one another.

Adjacent the electron ejector there is arranged a collector plate 20 having an aperture 21 for the passage of the electron beam going to the target. This plate is coated with a layer of fluorescent material and is electrically connected to the anode 3. This implies that the plate must either by made of metal, at least of a conductive material, or must be coated with a conductive layer. The plate may alternatively be the image-forming diaphragm of the electron-optical system.

Figure 4 shows what will be visible on the collector plate. The plate or a large part thereof is covered by a weak glow (in the region 22) produced by dispersion and chromatic aberration. With correct adjustment of the focal distance of the lens, the electrons which return from the focal spot at undiminished or substantially undiminished velocity concentrate in a brightly illuminated spot 23 beside the aperture 21. With respect to its shape and size, this spot corresponds to the cross-section of the beam 8 of which an image is produced on the target 2. The correct adjustment of the focal distance of the lens is that at which the spot 23 is as small as possible. A change in the focal distance causes the spot to spread and to become blurred.

As has been mentioned hereinbefore, the smallest beam cross-section, an image of which is required to be produced on the target 2, usually lies between the anode 3 and the diaphragm 4 of the ejector system. In this event, a collector plate disposed as shown in Figure 2 is spaced away from the lens by a smaller distance than the object of which an image is to be produced. However, when the difference in distance is not excessive, it does not appreciably affect the image definition, since, unlike the region between the lens and the target 2, in the region between the lens and the collector plate 20 the beams of the rays converging into an image point are very slender, so that a sufficiently sharp image is produced even in a plane which does not pass exactly through the beam peaks.

There may be a larger difference between the distance by which the image formed by the returning beam is spaced away from the target and the distance by which the electron ejector is spaced from the target. This is the case when the optical system comprises at least two lenses and the returning beam does not pass through all the lenses of the system. In Figure 1, for example, a second lens may be interposed between the anode 3 and the magnet system 7, which lens produces an intermediate image. If this intermediate image is real, the magnet system 7 must be located between the intermediate image and the lens 5. Consequently, the collector plate will be nearer the target 2. If the intermediate image associated with the ray beam travelling to the target is virtual, the beam of returning electrons produces a real image at a larger distance than in the absence of the second lens.

WHAT WE CLAIM IS:—

1. An X-ray shadow microscope including an adjustable electron-optical image-producing system, wherein in operation a first beam of electrons travelling from an electron ejector to a focal spot on a target is reflected as a second beam of electrons from the focal spot which second beam passes in operation through the optical system or through part of the stages which this system comprises and is collected on a fluorescent observation screen.

2. An X-ray shadow microscope as claimed in Claim 1, wherein the path of the second electron beam is separated from the path of the first electron beam.

3. An X-ray shadow microscope as claimed in Claim 2, comprising magnetic means for deflecting the electron beams.

4. An X-ray shadow microscope as claimed in Claim 3, wherein the said magnetic means is arranged to produce a magnetic field in a direction perpendicular to the path of the electron beams.

5. An X-ray shadow microscope as claimed in Claim 3, the electron-optical image-forming system of which includes a magnetic lens, wherein the optical axis of this lens is at an angle to the path of the said first electron beam.

6. An X-ray shadow microscope as claimed in Claim 5, wherein between the electron ejector and the magnetic lens there is disposed an electrically conductive collector plate provided with a fluorescent coating which plate has an aperture for passage at the first beam of electrons.

7. An X-ray shadow microscope as claimed in Claim 1, constructed and adapted to operate substantially as described herein with reference to Figure 1 or Figure 2, 3 and 4 of the accompanying drawings.

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865,050 COMPLETE SPECIFICATION
1 SHEET

This drawing is a reproduction of the Original on a reduced scale.

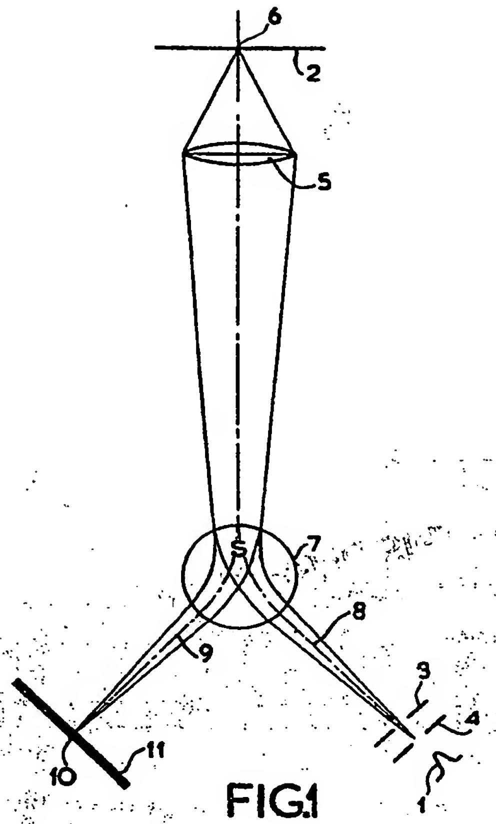

FIG.1

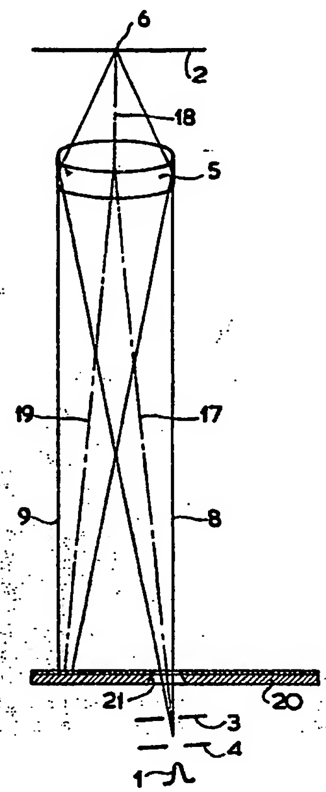

FIG.2

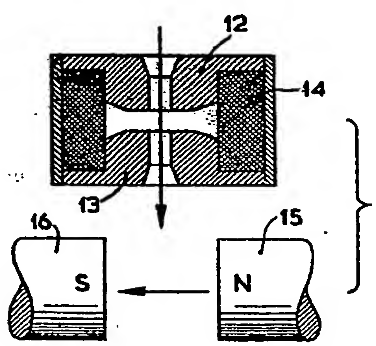

FIG.3

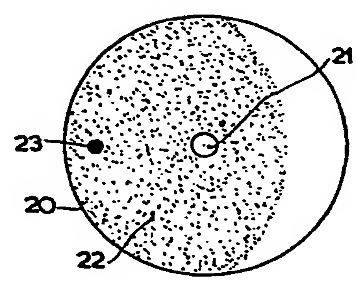

FIG.4